DEVELOPMENT OF A FUZING SYSTEM FOR A SUBMARINE LAUNCHED PYROTECHNIC SIGNAL

P. RAMSAY AND M. COXHEAD

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ABSTRACT

A safety and arming system, suitable for incorporation into a submarine launched pyrotechnic signal was developed to conform with submarine fuzing concepts. The experimental model interfaced with a key slotted, 3 inch diameter Submerged Signal Ejector and was developed to be compatible with operational procedures and standards in the Australian Oberon Class submarine.

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Cordite Avenue, Maribyrnong, Victoria 3032, Australia
Telephone: (03) 319 3887
Fax: (03) 318 4536

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AUTHORS

Peter Ramsay qualified with a Diploma of Chemistry in 1966 with a double major in Explosive Technology and Instrumental Systems Analysis. Before joining MRL he worked with the Government Production Facilities. He has extensive experience in the development of specialised equipment for the Australian Defence Forces which include explosive actuated devices and lately underwater electronic equipment for mine warfare data acquisition. His particular expertise now resides with system integration electronic design and design management.

Max Coxhead qualified in 1972 with a Certificate of Technology in Mechanical Design. He has extensive experience in a number of Government establishments in design and production engineering with an emphasis on the interfacing of explosive, mechanical and electrical systems. His particular expertise is with the development of explosive devices and underwater instrument structures design.

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DEVELOPMENT OF A FUZING SYSTEM FOR A SUBMARINE LAUNCHED PYROTECHNIC SIGNAL

1. INTRODUCTION

The development for the RAN of a Submarine Launched Marine Pyrotechnic Signal required the design of an arming system to comply with the current high level of safety standards applied to explosive filled ordnance. These requirements are of importance, particularly when considering the development of submarine pyrotechnics, because these items of ordnance are stored in and launched from an enclosed and restricted space. This report outlines the development of an experimental integrated safe arming system suitable for use with submarine launched pyrotechnic signals. Design parameters were selected which were compatible with the Submerged Signal Ejectors (SSE) used on the Australian Oberon Class submarines.

The explosive function of any submarine launched pyrotechnic device must be initiated solely by the integral fuzing system and then only when required by the user. Therefore the overall safety of a device must be managed by the fuzing system.

The marine pyrotechnic signal contains sensitive explosive materials and has the potential for unacceptable consequences should the signal function within the confines of the submarine. Loss of fighting capability may occur through injury to personnel or through damage to the ship's equipment through fire. Therefore the principles of operation and performance incorporated into the experimental design were required to preserve a high level of safety. Further, these features were to be capable of maintaining the pyrotechnic signal in a safe condition, without unacceptable degradation, throughout its service life.

In specifying the safety principles for the arming system, cognizance was taken of the philosophy of the Australian Ordnance Council as expressed in UK Ordnance Board publications [1,2].

2. DESIGN CRITERIA

2.1 Mechanical

The Oberon Class submarine is fitted with the UK 4 inch Submerged Signal Ejector. By inserting a loose fitting fibre-glass sleeve into the bore to reduce the internal diameter, this ejector can release most standard 3 inch NATO stores. Current design philosophy is to use this smaller (76 mm by 1.0 m) ejector. This was chosen as a design parameter for this signal.

The signal is to be capable of ejection from the submarine at depths down to 610 m. Allowing for manufacturing tolerancing, the mechanical strength of the fuze body should be sufficient to withstand both the hydrostatic pressure at 760 m depth of 9.2 MPa plus an additional pressure of 1.5 MPa produced by the water ejection system. These values provide the fuze body with a practical operational safety factor of 1.2.

The signal is ejected from the launcher by a high velocity jet of water directed onto the base of the signal adjacent to the fuze. The fuze hydrostatic sealing must be capable of surviving the impact shock generated by the water ram while the body experiences the mechanical interaction between the arming mechanism and the launcher barrel. The arming action must occur smoothly without inducing damage in the ejector, fuzing or arming systems. All hydrostatic seals must survive both the high pressure water impulse and then the slower reduction in pressure while the signal moves to the surface.

Any mechanical procedure undertaken within the ejector tube must not impede any sequential arming operation of the fuze, cause an obstruction or damage the ejector system.

Where electrical contacts are activated by the mechanical action, these must be self cleaning, self aligning and must not be susceptible to erratic mechanical action.

2.2 Safety

The requirement for safety of explosive filled ordnance requires that the fuze system maintain safety during transport, storage, handling and during the launch environment. The design should include a positive method of determining the safe or armed condition of the ordnance at any time during its service life.

Premature functioning of the signal within the signal ejector or immediately external to the submarine will not necessarily be hazardous. However, arming should not occur until the signal launch phase is complete and the signal has reached a safe separation distance from the submarine. Two independent safety features are required to ensure this.

A simple handling procedure is required to minimise the potential for operator error in an emergency.

2.3 Environmental Safety

The pyrotechnic material must remain in a safe condition in the event of mechanical failure of the safe arming assembly. The signal must remain safe or fail in a safe condition under all conditions expected to occur during its service life, in particular:

as a result of vibration experienced during land, sea or air transport,
after experiencing explosively induced underwater shock,
after being dropped from a height of 12 m,
after undergoing inadvertent immersion in sea-water,
after sustaining material damage to the body, or
after exposure to electromagnetic radiation.

3. DESCRIPTION OF FUZE ELEMENTS

The fuze (Figure 1) consists of three major functional assemblies. The first contains a removable transit safety pin and safe arming plug; the second is a mechanical arming assembly which interacts with the submarine's launching facilities; the third contains a hydrostat valve which unlocks only after sensing the low hydrostatic pressure near the sea surface.

These assemblies are partially contained within a cylindrical sealed body located in the base of the signal. Those components which are required to interface with the SSE are located at the rear of the fuze body and can protrude outside the signal's profile. The remaining items are contained within a sealed environment forward of the hydrostat's watertight bulkhead.

The three assemblies are integrated for serial use and each is required to sense and react only to its own specific environment. When these assemblies function in the correct sequence, electrical switch elements operate to link a battery and explosives components to the electronic firing circuits.

The following is a description of the elements contained within these assemblies and their major design requirements.

3.1 Fuze Body

The fuze body contains all of the mechanical and electrical safe arming assemblies. It is free to float about two 'O-ring' seals within toleranced limits in the end of the outer tube of the signal. The force exerted on the fuze assembly during launch is taken by the single retaining bolt holding the fuze to the body of the signal. The

force of payload launch has been measured at 6.4 x 10^3 N. The integrity of this bolt has been confirmed by a test with a load four times this value.

3.2 Safety Pin and Safety Plug

When used together these items satisfy the requirement for primary safety (1). The safety plug disables the safety and arming mechanism and provides appropriate safety against unintentional arming within the environs of the SSE. It is designed for both ease of insertion into the fuze base should the launch be aborted and for positive release after the signal is loaded into the SSE. The plug is of non-symmetrical design to ensure insertion only in the safe orientation.

Insertion of the spring steel primary safety pin locks the safety plug in position and applies a load-sharing force of 50 - 150 N with the retaining spring to close the hydrostat valve. The highest level of safety is provided with the primary safety pin inserted.

3.3 Safe Arming Assembly

This assembly contains the major items of bore-rider, arming latch, interconnecting actuator and torsion spring.

The arming latch is made from teflon to facilitate ease of movement against the fuze body and internal self-locking load pin.

The bore-rider is designed to operate as a reverse loaded beam and to withstand shock loadings and movement against the internal surface of the launch tube. It is configured with sufficient movement to overcome the relative tolerances between the launch tube bore and signal outside diameter.

The interconnecting actuator limits the relative movement between bore-rider and arming latch. It has been designed to supply the reaction force between these two items. In the event of damage to the bore-rider it precludes extension of the arming latch and incorrect release of the hydrostat valve.

A force of 8 N supplied by the arming torsion spring restrains the bore-rider within the body line of the signal by its reaction against the inside wall of the launch tube and simultaneously extends the arming latch into the launch tube keyway. The value of 8 N reflects a balance between the physical constraints of the spring and a force that is sufficient to maintain the latch within the keyway during the rigors of launch.

3.4 Guide and Support Pad

The guide and support pad transfers the force generated by the retaining spring onto the neoprene O-ring seal within the hydrostat valve. Because of the eccentric position of components in the fuze body, the force generated by the retaining spring is not uniformly distributed across the support pad. It is essential that any eccentric

loading on the hydrostat valve be eliminated and that a controlled uniform distortion of the hydrostat seal be generated. To achieve the require load distribution across the hydrostat valve, the support pad is designed with a complex curved surface which forces the retaining spring into a predetermined configuration, and requires that this element be assembled with a specific orientation.

The profile of the load bearing surface can be calculated using the standard "dummy load" technique (3). See Appendix A.

3.5 Retaining Spring

The retaining spring uses a U shaped beam loading technique to apply the sealing load to the hydrostat valve. When manufactured from high quality spring steel, a 2.5 mm diameter spring exerts a force of 430 N when deflected 2.09 mm at the centre line of the hydrostat valve.

3.6 Battery Assembly

Two Mk 72 sea-water batteries are retained by the battery holder. They are connected in series to generate 3 Volts DC and supply electrical energy to power the electronic circuit and to ignite the launch propellant charge. The battery assembly is configured for the minimum area (19.5 cm^2) that can be presented to the hydrostat valve. This permits the largest signal-to-hydrostat diameter ratio to provide maximum mechanical strength to the safe arming assembly.

3.7 Hydrostat Valve

During the signal's rise to the surface, the batteries are kept dry and inactive until the appropriate depth is reached. The hydrostat mechanism is used to control this function and to determine the depth at which sea-water is permitted to enter the base of the fuze and react with the batteries.

The hydrostat valve consists of a circular aluminium plate and and included O-ring seal. The plate is configured to promote its free movement away from the naturally rising signal when the valve commences to open and to limit the compression of the O-ring seal to 30%.

In conjunction with a double-leaf spring, both the hydrostat springs are designed to exert a total force of 125 N through the base of the centrally located battery holder onto the hydrostat valve. The springs have a loaded extension of 2.0 cm to ensure that the Mk 72 sea-water batteries are completely wetted after they have been relocated outside the fuze body. After battery deployment, each spring maintains an extension force of 4 N to positively lock the battery holder into the end of the sliding contactsprings. This alleviates contact bounce and provides a sliding abrasive force to clean the electrical connections carrying current from the batteries.

3.8 Sliding Contact Springs

These two springs are configured to exert a decelerating force on the battery containers toward the end of their outward travel. They also assist with locking of the electrical contacts. After the batteries have been deployed, deformation at the base of the spring caused by the battery assembly is designed to be close to, but not to exceed, the elastic limit of the phosphor bronze element. This assists in maintaining a low resistive electrical path and inhibits shock fracture of the springs.

Both of the springs are located on and rivetted to the printed circuit board.

The contact springs have an important secondary safety role. Should the sealing rings fail and sea-water enter the fuze body, they maintain the isolation of energized batteries from the electronic circuits.

3.9 Double-Leaf Spring

Although the double-leaf spring assists in applying an additive force of 5 N on the hydrostat valve, its main function is to provide a secondary safety feature. While the hydrostat valve remains closed, it applies an electro-mechanical shorting link across the pyrotechnic match-heads. The two phosphor bronze arms react in a self cleaning mode against the copper lugs on the printed circuit board.

4. FUZE OPERATION

The primary safety pin, also termed the transit safety pin, is removed from the base of the fuze to permit the signal to be inserted into the breech of the SSE. Orientation of the signal within the launcher is achieved by locating the fuze retaining bolt in the guide groove. Once the signal is correctly inserted into the launcher, the secondary safety plug is removed by pulling the attached cord. As the plug and cord fall free of the breech the safety and arming mechanism is activated.

The removal of the secondary safety plug (Figure 2) releases the spring energy stored within the arming actuator. Both the restrained bore-rider and the arming latch are now free to deploy outwards with the arming latch relocating into the slotted keyway of the ejector tube.

After launch, during the forward movement of the signal along the ejector tube (Figure 3), the arming latch reaches the blind end of the guide keyway and the latch is tripped. This action releases the external force exerted on the hydrostat by the hydrostat retaining spring and permits the safety and arming assembly to swing rearward and clear the area directly below the hydrostat valve. The sea-water pressure is now the only retaining force on the hydrostat valve and maintains the valve in the closed position.

Final arming commences at a depth of approximately 5 m below the surface. Here the force exerted by the sea-water on the hydrostat valve and the force of the hydrostat springs are equal. A further small drop in water pressure permits these springs to force open the hydrostat valve (Figure 4) and the battery pack moves backwards into the sea-water. This action simultaneously connects the rapidly energizing batteries to the circuit connectors and removes the electro-mechanical short from the match-heads embedded in the payload launching charge. Mechanical arming is then complete.

If the launch is to be aborted, the signal can be removed from the ejector system, even though the secondary safety plug has been removed. The fuze can be withdrawn from the breech; this action allows the torsion spring to force the bore-rider outside the body of the signal which withdraws the arming latch via the arming actuator (Figure 5). This removes the only means of triggering the system. The exposed bore-rider prevents the signal being reinserted into the ejector tube until the safety plug is replaced. This ensures that correct safety procedures are followed. The signal may be either reloaded or safely stored.

5. SUMMARY

A safety and arming system has been developed for a submarine launched marine signal. It was developed to meet the current requirements for safe arming of explosive ordnance by using a two-stage system to sense the environment. The launch environment is sensed by detecting the internal bore surface of the launch tube and the rapid movement of the signal during launch. Final arming of the signal takes place at a depth of 5 m from the surface with the drop in hydrostatic pressure.

The fuze design permits the signal to be removed from the submarine launching equipment in a configuration which precludes unintentional arming because the signal cannot be reloaded into the launcher or conveniently handled without first reinserting the safety plug. Even severe damage to the protruding bore-rider will not cause the fuze to arm. Should the signal be damaged seriously enough to allow the ingress of sea-water, the firing circuits will not activate as the batteries remain electrically isolated and the electrical igniters are shorted.

6. REFERENCES

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2. UK Ordnance Board Proceeding 42240, Safety of fuzing systems, 24 May 1983.

3. Popov, E.P. (1978). Mechanics of materials. New York: Prentice Hall.

4. Parker 'O-Ring' handbook, Parker Seal Company, Lexington, Ky., 1975.

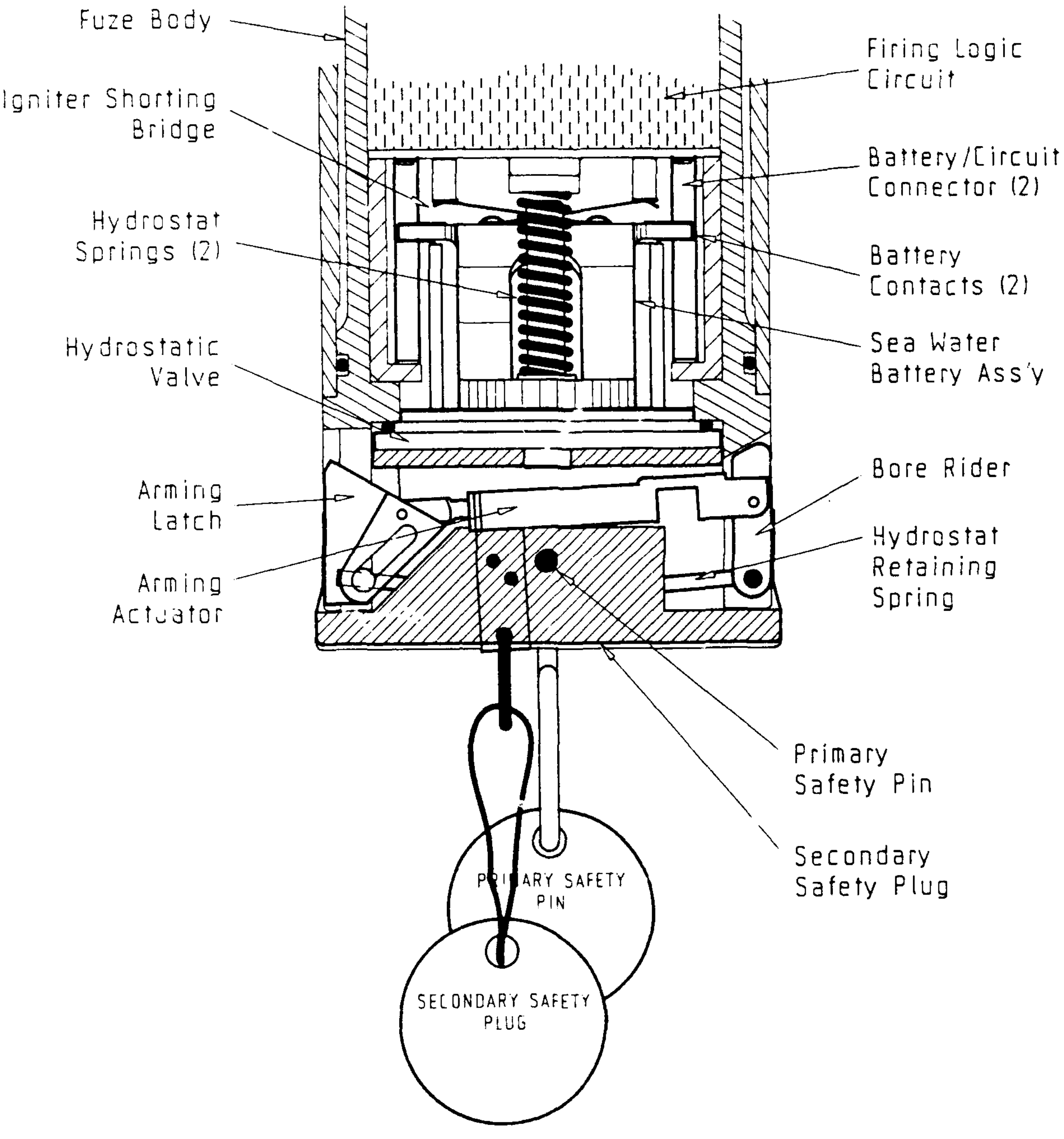

Figure 1   Fuze Assembly

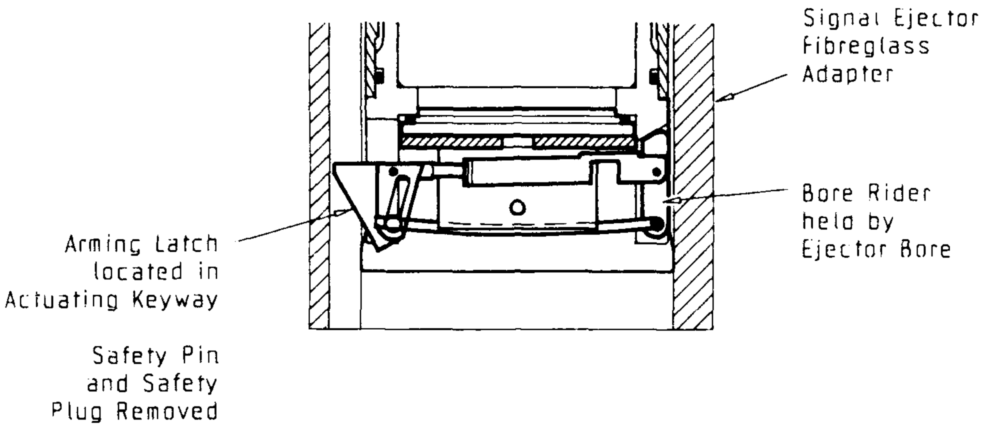

Figure 2 Fuze state prior to launch

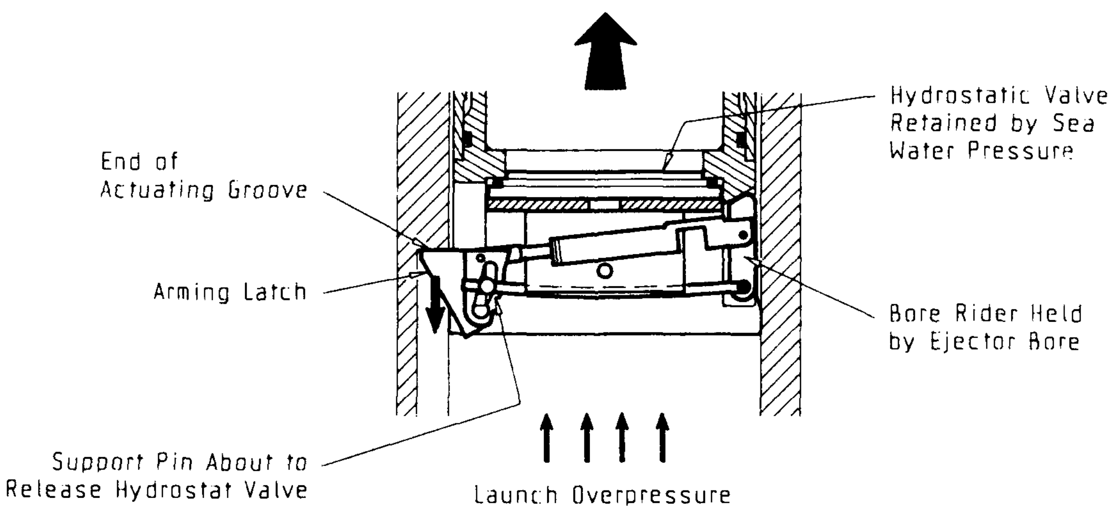

Figure 3 Fuze state during launch at moment of hydrostat release

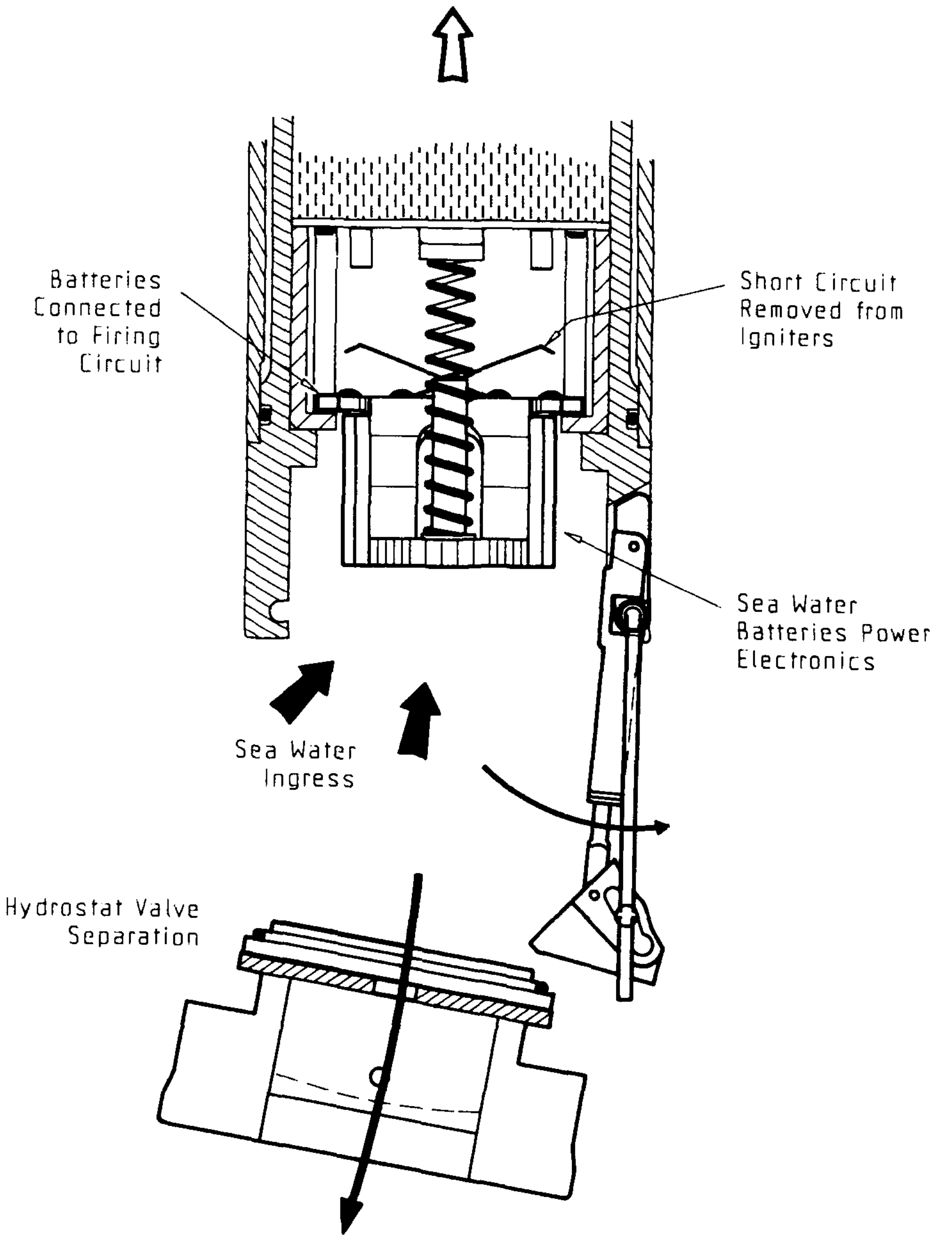

Figure 4 Fuze state at hydrostat opening

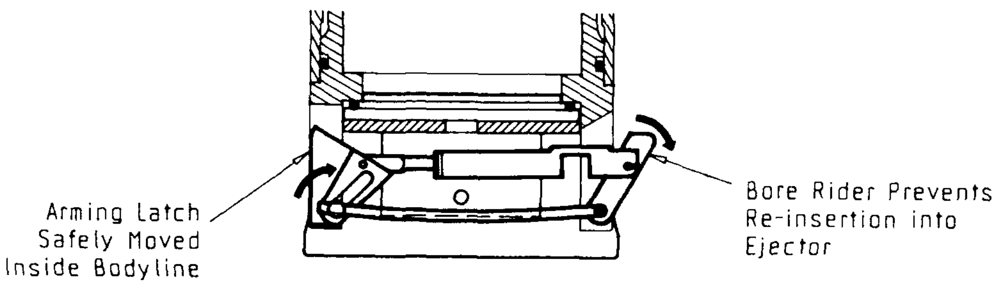

Figure 5 Fuze state after removal from signal ejector

APPENDIX A

Calculation of Profile of Support Pad

The profile of the load bearing surface can be calculated using the standard "dummy load" technique [3].

By assuming an evenly distributed force over the contact area between the beam-spring and the plastic guide and support pad, the equation can be determined for the resultant deflection curve of the spring center line. As a corollary this provides the contour required in the guide and support pad such that the resultant bearing force at the spring-plastic interface is uniformly distributed. A diagram of the forces acting on the proposed spring profile while it functions as a beam are shown in Figure 6.

The forces illustrated as Fr1 to Fr4 are the reaction forces at the support points which are produced by the real and dummy loadings.

w is the load per unit length of the beam spring and is given by

$$w = \frac{\text{Total load}}{2d}$$

where d is the length over which the spring is distorted.

'M' is the moment at point 'a' produced by the uniformly distributed load 'w', and can be expressed as a function of 'a' and 'w'. The value 'm' is the moment at point 'a' produced by the application of a unit dummy-load at point 'X', and is represented in an equation by 'a' and 'X'.

The deflection 'Y' at point 'X' along the spring can be given by

$$Y = \int_{a=O}^{a=L} \frac{M*m}{E\ I}\, da \qquad (1)$$

where the values between a=O and a=L are the limits of the length of distortion of the spring. 'E' is the elastic modulus of the beam spring and has a value of 207 GPa. 'I' is the moment of inertia of the circular section of the beam spring with a radius 'R' and can be expressed as:

$$I = \frac{\pi * R^4}{4} \qquad (2)$$

For a beam spring with a radius of 1 25 mm the total force applied against the supporting plastic pad is the sum of the force necessary to compress the hydrostat "O" ring seal plus that necessary to balance the force exerted by the hydrostat spring and double leaf spring.

The force necessary to seal the hydrostat valve during transport and storage is achieved by a 7.5% compression pre-load on the "O" ring seal of approximately 300 N [4]. The hydrostat and double leaf spring system exerts a combined force of 130 N against the hydrostat valve. The total compressive force which must be produced by the beam spring is then 430 N, representing a distributed load 'w' of 5375 N/m on each of the two springs.

The resultant equation (3) is derived using the above technique by integrating equation (1) and by substituting the value for the moment of inertia from equation (2). The magnitude of deflection 'Y' of the spring is a function of the distance 'X' from the end of the spring. The values of 'X' and 'Y' are expressed in metres and incorporates the above spring physical dimensions and characteristics.

$$Y = 421.94\,(X - 0.0115)^4 + 0.0994\,X - 35.53\,X^3 \qquad (3)$$

This equation generates an unsymmetrical complex profile which when engraved into the guide and support pad, requires that this element be assembled with a specific orientation.

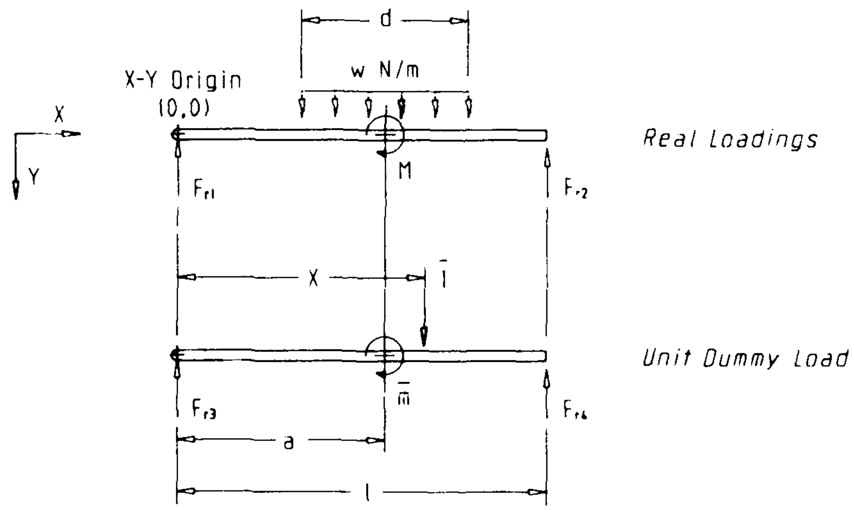

Figure 6 Load on Retaining Spring

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AUTHOR(S)

P. Ramsay and M. Coxhead

CORPORATE AUTHOR

DSTO Materials Research Laboratory
PO Box 50
Ascot Vale Victoria 3032

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